Upgrade of the CMS Barrel Electromagnetic Calorimeter for the LHC Phase-2

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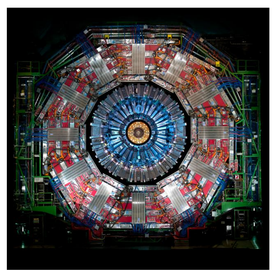
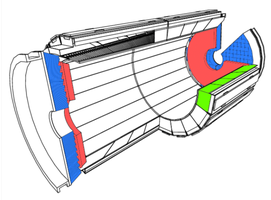
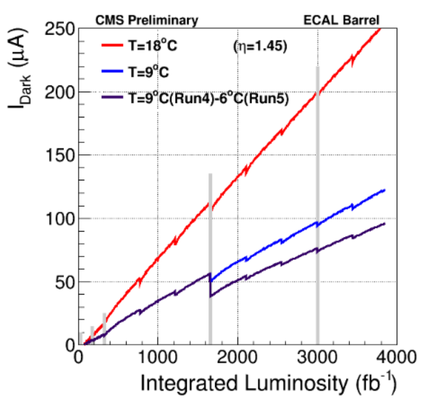
DIGITAL VERSION

Introduction

The **CMS electromagnetic calorimeter (ECAL)** consists of 75848 **lead tungstate (PbWO4) crystals**, arranged in a barrel (**EB**) and two end-caps (**EEs**), and a silicon-sensor **preshower**. It serves a crucial role in the successful CMS physics program with **precise time and energy measurements of electromagnetic particles** from high-energy collisions of the LHC at CERN.





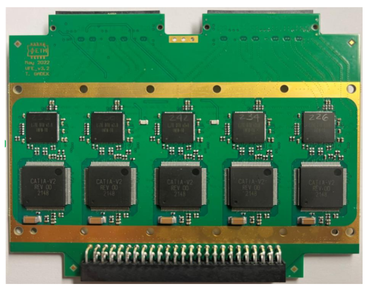


In 2029, the LHC will start its High-Luminosity Phase-2 era, providing an instantaneous luminosity of 5×10^{34} cm^{-2}s^{-1} with an average of 140-200 simultaneous collisions to reach an integrated luminosity of 3000 fb^{-1}.
The CMS ECAL will need to be upgraded to operate in such conditions. The endcaps will by replaced by the High Granularity detector.
In the **EB, the crystals and their APDs will be retained**, but operated at 9℃ to reduce the APDs noise. The electronics will be fully upgraded to cope with the 7.5 fold increased CMS trigger rate with the goal of achieving a timing resolution of 30 ps for particles with energy E $\geq$ 50 GeV.

Front-end boards

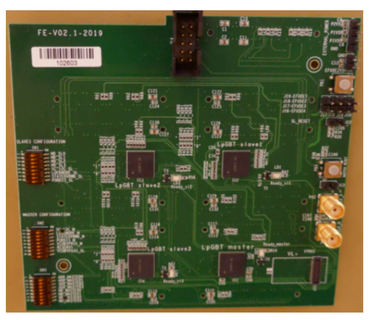
VFE

The Very Front-End board (12240 units) is connected to the crystals APDs through a motherboard retained from the current ECAL. Each VFE houses five CATIA and LiTE-DTU chips to **read, amplify, digitize and transmit the signals** from five crystals.



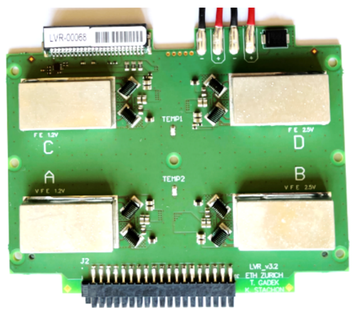
FE

The Front-End board (2448 units) collects the signals of five VFEs and sends the data to the back-end system via **10 Gb/s optical links**. The clock and control signals are managed by **four CERN Low-power Gigabit Tranceiver (LpGBT) chips**.



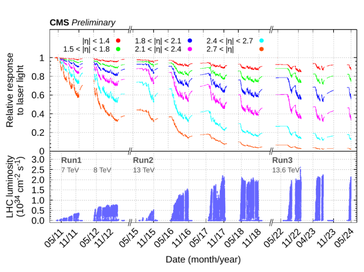
LVR

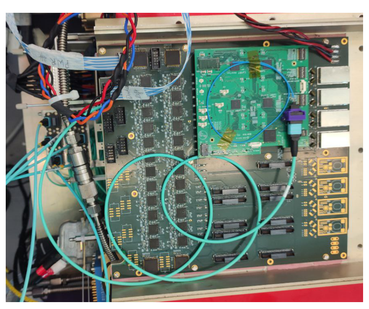
The Low Voltage Regulator (2448 units) **distributes the power** to the VFEs and FE. It houses **radiation hard DC-DC converters** to supply the required voltage to the ASICs. The **power consumption is halved** w.r.t to the current ECAL.

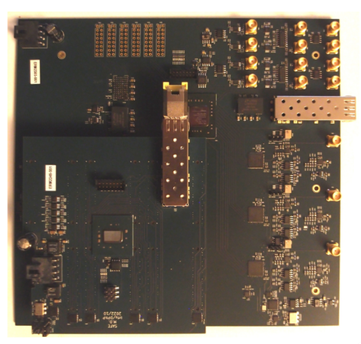


Laser monitoring system

The Laser monitoring system constantly monitors **crystals transparency changes** using **PN diodes as reference.**
For **Phase-2**, the number of **PN diodes is doubled** (864 units). They are hosted in the HL-**Front End Module** (FEMs) (422 units) with the **new charge pre-amplifier MONACAL ASIC**.
The HL - **Monitoring Electronics read-out Module** (36 units) receives the analog signals from the FEMs, digitizes them with the LiTE-DTU at 80 MS/s and sends data to the back-end electronics through standard FE boards.
The **interface with the trigger and DAQ** is managed by the single new **Laser Monitoring Board** employing a commercial FPGA.







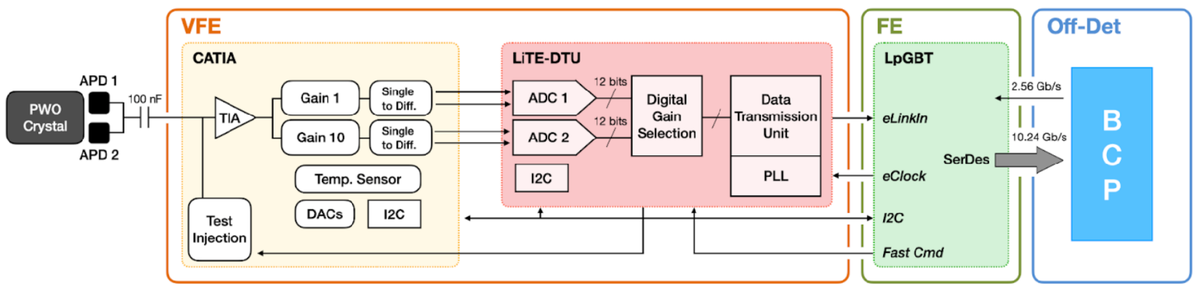
Front-end ASICs

CATIA

- Calorimeter Trans-Impedance Amplifier
- radiation tolerant 130 nm CMOS technology
- dual gain outputs $\times 1$ and $\times 10$
- range from tens of MeV to 2 TeV
- signal shaping time $\mathcal{O}(20)$ ps

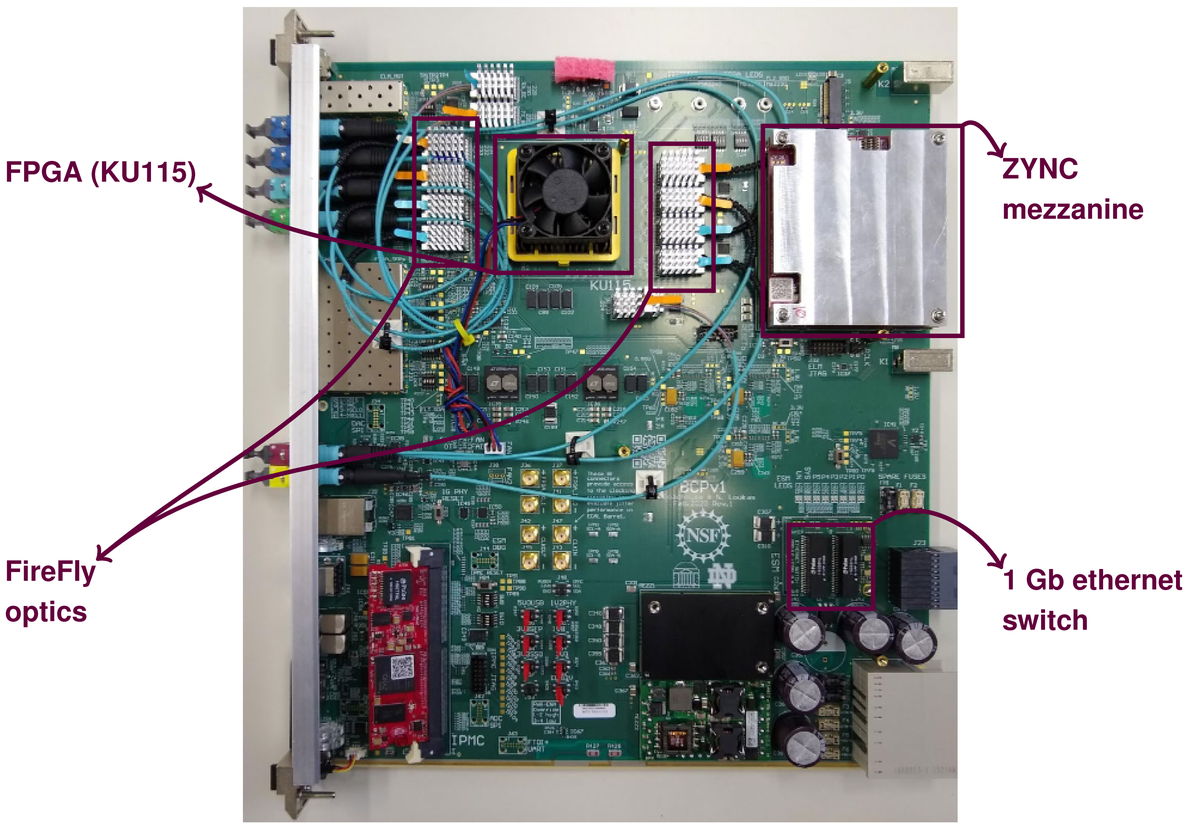
LiTE-DTU

- Lisbon-Torino ECAL Data Transmission Unit
- radiation tolerant 65 nm CMOS technology
- two commercial 12 bits 160 MS/s ADCs
- lossless data compression
- 1.28 Gb/s serial link

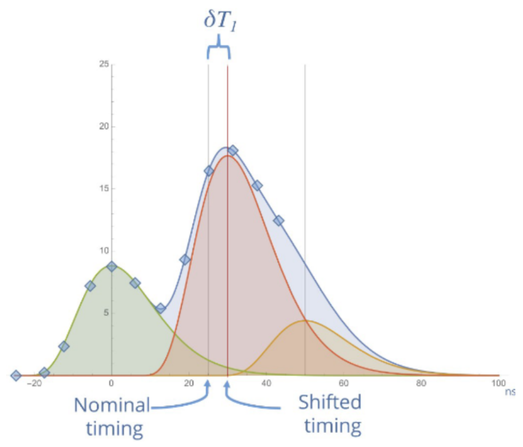


Back-end board

The back-end electronics consists of the new the **Barrel Calorimeter Processor (BCP)** board. It is located in the CMS service cavern, thus not requiring a radiation tolerant design. Each card handles 600 channels, with a total of 108 units required to cover the whole ECAL.
It is a custom designed Advanced Telecommunications Computing Architecture (**ATCA**) board embedded with a large **Xilinx Virtex Ultrascale Plus VU13P FPGA**.
The prototype board BCP v1 with the Xilinx Kintex Ultrascale KU115 FPGA is used to develop the firmware and test the interface with the FE and the DAQ.

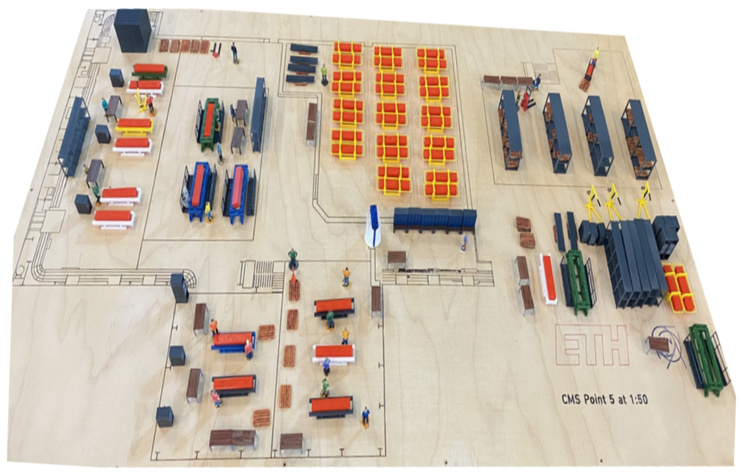


It **provides the clock and control signals** for the front-end electronics, receives the signal of each crystal via optical fibres and **generates** two sets of **trigger primitive** (TP) for the L1 trigger, one for single crystals and one for clusters.
Each TP contains the **position**, the **transverse energy** and the **time** measured with a linearized multifit-timing algorithm. A **spike flag bit** is added using the differences in the pulse-shape and energy topology discrimination.
The connection to the DAQ and the FE electronics is made with SAMTEC FireFly optics transmitting up to **25 Gb/s**.
The board is controlled via a Xilinx ZYNC FPGA mezzanine running Linux.
The CMS hadronic calorimeter will use the same back-end board.



Current status and future plans

- **pre-production** batch of the final version of the **front-end ASICs under evaluation**
- **design** of the **front-end boards near completion**
- **excellent preliminary results from beam tests** with near-to-final version of all the components of the upgraded readout
- **firmware and layout of the BCP final version v2** board almost finalized
- the **Enfourneur2**, the upgraded version of the extraction and insertion tool of the ECAL 36 supermodules (SMs) weighting 3 t each, is **under commissioning**
- first **prototypes of upgraded laser monitoring components fully operational**, defining placement and cabling
- the extraction of the SMs is foreseen to start in the second half of 2026, the **electronics refurbishment** and the re-insertion are planned to be **completed by mid 2027**, with ECAL commissioning in 2028
- definition of service requirements for the **upgrade integration area** (mockup)



Main references

[1] CMS Collaboration, "The CMS electromagnetic calorimeter project". Technical Design Report CMS. CERN, Geneva, 1997.
[2] CMS Collaboration, "The Phase-2 Upgrade of the CMS Barrel Calorimeters". Technical Design Report CMS. CERN, Geneva, 2017.
[3] T. Reis on behalf of the CMS Collaboration, "CMS ECAL upgrade for precision timing and energy measurements at the High Luminosity LHC", *J. Phys. Conf. Ser.* **2374** (2022) 012072, doi = 10.1088/1742-6596/2374/1/012072

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